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14. ABSTRACT

This report results from a contract tasking Institute of Mechanics, Bulgarian Academy of Sciences as follows: The grantee will use plasma and magnetic field interplanetary data generated from orbiting spacecraft to develop real-time models of the earth's ionosphere. This will provide detailed knowledge about the Magneto Hydrodynamics (MHD) discontinuities that occur due to the solar wind, and its effects on communications.

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Institute of Mechanics

GEOSPACE HYDRODYNAMICS LABORATORY

Final Report

NEW TECHNIQUES IN SPACE WEATHER FORCASTING

Effort sponsored by the Air Force Office
of Scientific Research,
Air Force Material Command, USAF,
Under grant number FA8655-05-1-3024

Principal investigator:
Monio Kartalev

Sofia, Bulgaria,
May, 2006

Project team:

- **Monio Kartalev** – PI
- **Krum Grigorov -** basic and interface & web software
- **Murray Dryer** (US) - scientific consultant
- **Hristo Iliev** - basic software, Linux cluster developing and managing
- **Lyuba Bundova -** scientific modeling and software
- **Eugenia Stoimenova -** scientific consultant in statistics
- **Polya Dobreva -** scientific modeling and software
- **Galina Kangalova -** accountant

CONTENTS:

I. OUTLINE OF THE ORGANIZATION / TIME SCHEDULE ASPECTS

1. The proposed by PI and later accepted working program foresaw one year work.

After the acceptance of the project on 1 May, 2005, the PI was asked for (and he accepted) shortening the project duration till 30 October 2005, or shortening to 6 months duration.

2. Financial conditions:

Total amount of award:	$ 19400.00
Advance payment:	$ 12000.00
Payment made after receipt and acceptance of a Medium Term Report	$ 3000.00
Payment after receipt and acceptance of a final report	$ 4400.00

3. The very essential element of the project goals - the development of an Internet-based real time/interactive solar wind data interpretation system – requires appropriate computer equipment. A part of the advance payment was planned for purchasing this equipment, but the routine procedures took some time (including 45 days needed to Bulgarian bank to pay money for the already received check). As a result, the advance money was available only at the end of August. Then we had to wait more then a month for the appearance in Bulgaria of the chosen platforms based on a new dual-core 64-bit Pentium-4 processor with excellent performance/price ratio. Thus we had available the final project hardware only in October and were able to install and elaborate the appropriate 64-bit operational system and other basic software actually only about the end of October. The obtaining, installing and setting-up of the needed Fortran (with environments), Matlab and so on took us even much more time.

4. The Institute of Mechanics hadn’t the capability to help the team with advance financing for earlier purchasing the equipment. That’s why we utilized the period May-October (as described in particular in the Mead Term Report) performing the possible activities, based on the available Windows computers & one old

small computer, where 32-bit simpler Linux OS were installed temporary. These activities included: development and testing a separate fast internet connection, especially devoted to the project; taking experience on the new to the team Linux operational system; working on the algorithms; working on some papers.

5. The team faced some “non-planned” difficulties (especially with setting program languages, 32/64-bit Matlab problem and so on) after changing, together with the hardware (from October-November), the 32-bit operational Linux system by 64-bit one. Practically everything prepared and tested already on 32-bit variant needed additional work again.

6. A decision was taken to develop in parallel interactive online work with both ACE and WIND archive data in order to provide to the users a comprehensive opportunity to follow (when possible) the spatial development of the solar wind structures. This led to changing the used databases with all the following new not principal but taking time technical problems.

7. Some essential time delay (2-3 months) was caused by the decision to consider the non-planned problem of the estimates of the effective solar wind polytropic index, using single spacecraft measurements, which could become an additional tool in identifying the observed solar wind structures. The result is developed algorithms and submitted to JGR paper (with positive first reviewer’s comments already).

The total effect of these circumstances is that the present Final report is presented in the beginning of May, or really about 6 months after starting of “full value work” on the project in October - November.

II. FACILITIES & EUIPMENT & BASIC SOFTWARE ACTIVITIES after October – November 2005

Hereby we describe the hardware base that was set up during the course of the project and that serves as our computational foundation.

Design Goals

The main goals that we pursued in designing our system are high performance, high availability, and usage of open standards, enabling easy workload management, ease of system use, low overall cost and possibility of further expansion.

Hardware

For the cluster system three single processor dual core 64-bit Intel Pentium D machines were set up. Each machine features 2 GB of dual-channel RAM, 160 GB Serial-ATA hard drive (for reduced cabling and extended performance) and one 1000 Mbps Gigabit Ethernet adapter. Dual core Intel processors were favored because of their excellent capabilities of performing outstandingly fast mathematical calculations and because of the availability of free and professional level optimizing compilers and development tools for the Linux OS. Providing two cores in a single processor unit reduces the overall heat dissipation and also removes some memory bottlenecks.

Operating system

For the host operating system we have chosen the 64-bit Fedora Core 4 Linux distribution. Fedora is one of the many Linux distributions, based on the RedHat Linux known for its robustness, easy administration and broad choice of many prepackaged open-source tools. Also Fedora Core 4 Linux is free of charge and provides means for easy online update and upgrade. The system consists of 64-bit GNU/Linux kernel together with many prepackaged open-source tools and utilities. Because the packages can be chosen during installation and afterwards one can easily configure and optimize the system for his specific needs – one can either build a sever or desktop system or one that can serve both purposes (like we do).

Desktop Environment

For the GUI part of the desktop we have chosen the industry standard X Windows in its free and open-source incarnation X.org. Together with the GNOME desktop from Ximian and Sun Microsystems we have built a robust and friendly graphical user environment that is both easy to use and provides excellent Internet/Intranet integration. The integrated SAMBA client allow for easy access to the other Windows-based machines in the laboratory while the SAMBA server serves for the reverse purpose.

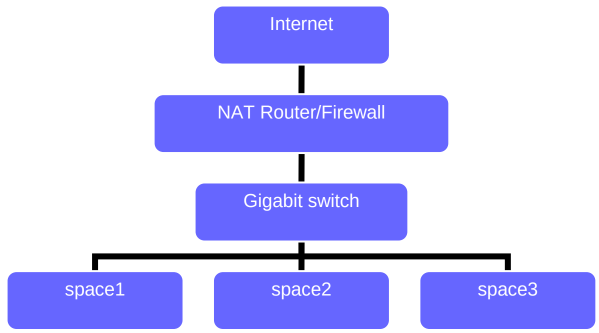
The OpenOffice.org office suit is used for viewing and editing documents – texts, electronic spreadsheets, presentations, etc.

The Eclipse IDE is installed and serves as basic development environment for developing Java, C and C++ codes. Unfortunately the FORTRAN development plug-in Photran is still quite underdeveloped so we still have to use MS Windows development tools for debugging our FORTRAN codes. We hope that in the near future Photran will evolve into a full-blown development environment for the

FORTRAN programming language and we will eventually switch to using it for our everyday development and debugging process.

Network Topology

The following networking layout was implemented for the purposes of this project.



The three machines are connected through high-speed low-latency Gigabit Ethernet switch and also NATed and firewalled Internet connection is provided. The NAT also has a firewalling side effect that comes handy and practically at no price.

Software

In order to make the results of the model accessible via the World Wide Web (WWW) we installed the Apache WEB server. Despite of its open-source nature Apache is one of the leading production class WEB servers and so it was chosen for the task. Apache features easy configuration, vast number of extension modules and presents little overhead to the system.

The 64-bit Intel FORTRAN Compiler (IFC) version 9.0 for Linux was chosen for part of the development process. IFC is known to produce highly optimized for the recent Intel processors native code that often runs 20% to 30% faster than code, produced by other free development tools (e.g. g77 or g95 from the GNU Compilers Collection). IFC is a professional class development tool that Intel has made freely available to the open-source community if it is to be used for non-commercial applications, e.g. non-profit scientific research like the one we do.

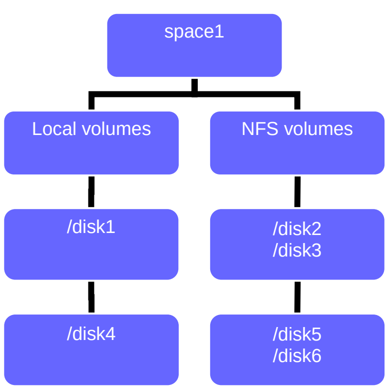
As part of the model is written in Matlab language we have chosen the 32-bit Linux version of Matlab 7 which we had available at that time. With some

tweaking Matlab was able to run in the 32-bit emulation mode of the 64-bit host operating system. Unfortunately we do not have the 64-bit Matlab version and cannot benefit from the full capabilities of the processors. Nevertheless the Windows version of the code was adapted, develped and successfully runs under Linux as an automated tool. The periodical scheduler *cron* is used in order to ensure the proper update of the model data via regular fetches of data from the Internet and its proper processing. The model programs were actively tested and verified under the new Linux environment.

Batch Queue

In order to distribute the computational load we implemented a batch queue environment based on Torque. Torque is an open-source version of the free OpenPBS batch queue system and allows easy allocation and management of resources in a cluster-like environment. The three dual-core machines behave like 6 logical CPU-s, each of them capable of executing one task at full speed without interfering with the tasks on the other CPUs. Our setup consists of one server node that runs pbs_server and pbs_sched (Torque's server and scheduler used for job submissions and control) and three execution client nodes running pbs_mom (Torque's execution client), one of them sharing the same physical computer with the server node. When an interactive task is submitted through the WEB interface or a new data block is automatically fetched from the Internet by the cron scheduled tasks, a new job is created and submitted to the queue system. The queue scheduler then finds an idle execution node and runs the job there.

Network File System



In order to simplify the transmission of job files and data between the computing nodes and the server node we use NFS (Network File System) mounted shared file systems. Each node exports a set of two file systems to the other two nodes and also imports both their exported file systems. Thus a consistent environment is created on each node allowing seamless access to the data files from each computing node. We can submit job file that reads from and writes to the same logical path without concerning on which node the job is actually executed. The usage of a gigabit network connection makes access to remote

file systems just a little bit slower than accessing local file systems. Actually the network outperforms the disk drives in physical bandwidth but the processing overhead of the in-kernel network stack adds to the disk latency and so the network file access is a little bit slower than the local file access.

Protection for the Outside

Because the Internet is a hostile environment and because NFS can export sensitive data we used NAT separation of the internal network from the Internet. No external connection is possible from outside to a server in the Intranet if the connection is not specifically allowed in the configuration of the NAT router. Thus only HTTP connections to port 80 and Secure Shell connections to port 22 are allowed.

Parallel Environment

A parallel MPI (Message Passing Interface) environment was set up for future use. MPI allows the creation of parallel programs for distributed memory machines (like clusters of workstations or dedicated computing nodes). Up to now our programs are completely serial but we are looking forward to parallelizing them in order to add some more processing to the data model that will increase the precision of the simulations without significantly affecting the execution time. OpenMPI (a descendant of LAM) was chosen as a MPI implementation because our primary target LAM is no longer developed in favor of OpenMPI. The latter is known to provide full support for the MPI-1 specification and also covers most of the MPI-2 specification. OpenMPI also integrates seamlessly with the Torque batch system.

Because of the dual-core processors we can also develop multithreaded programs using the OpenMP standard for writing parallel programs for shared memory machines. OpenMP is supported by the Intel FORTRAN Compiler v9.0 for Linux. We will target the inner loops of our model code for parallelization and will eventually achieve faster execution of the code and so will increase the interactive response of our WEB based model.

Software, ensuring the remote access and automated web applications

A very basic goal of the project is creating web site permitting remote work with our models and data bases via Internet access (Fig. 1 from the Mid term report).

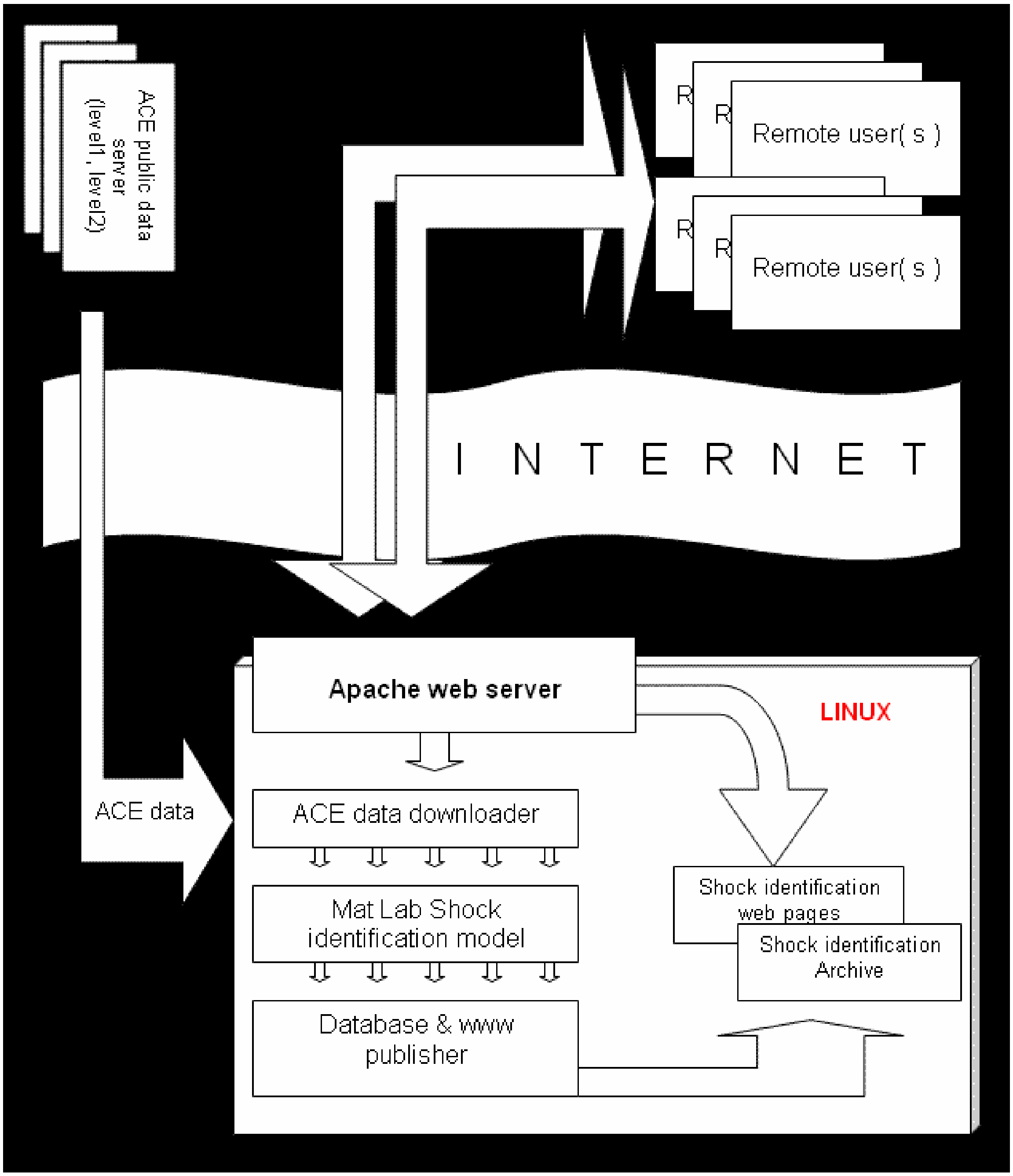
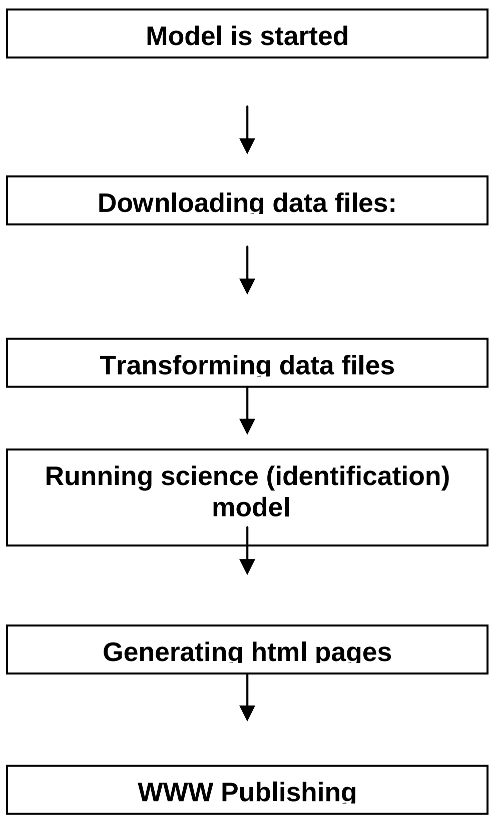


Fig.1 Schematic description of the system performance (the case of ACE data)

The site has two main functionalities:

- It shows the results of our model, runs with the latest data obtained from the ACE spacecraft.
- It allows users to run specific models for given date and time, allowing them to experiment with our models.

Follows a diagram of model (program) execution flow.



Although both functionalities share some common tools they significantly differ in both the tools used to prepare the data for the science model and the science model itself.

ACE latest data:

1. We use the Linux crontab service to run our ACE model periodically.
2. When the model runs first it downloads the latest available ACE data from http://sec.noaa.gov
3. The data files are transformed from the original format to our internal data format that is used by our science model.
4. The science model is started; it takes the transformed data files as input and produces output data file, describing found shocks, and several plots of the input data.
5. Afterwards, the output data and plots are combined together with html files, forming a unified web page.
6. Finally, the web page is published on our web server at http://space.nat.bg/last/index.htm

Interactive data interpretation models:

1. On our site the users from all over the world, can start our models for given time and date. This can be done from the following web page http://space.nat.bg/date/input.htm
2. When the user invokes our models, the web server accepts the user input and starts a CGI script that parses the input and starts one of the defined models.
3. Depending on the model and input date and time, data is downloaded from one of the following servers:
   ACE L1 data - http://sec.noaa.gov
   ACE L2 data - http://www.srl.caltech.edu
   Note: Currently ACE L2 data are taken only from the NASA CDAW data base:
   ACE and WIND data – http://rumba.gsfc.nasa.gov
4. The data files are transformed from the original format to our internal data format that is used by our science model.
5. The science model is started; it takes the transformed data files as input and produces output data file, describing found shocks, and several plots of the input data.
6. Afterwards, the output data and plots are combined together with html files, forming a unified web page.
7. Finally, the web page is published on our web server and the user is automatically redirected to the result page

Developed tools:

- Data downloader tools - these tools are written in C programming language and can be categorized as custom HTTP clients. Their purpose is to retrieve data from the public servers that provide ACE or WIND data. Due to the fact that we get the data from 3 different servers, we currently have created 3 different tools, each designed for one of the servers. Although there are 3 tools they share the same process model. The process is divided in 2 parts. First a request is sent asking for the exact location of the data file for given time period. When the server responds with either the location of the data or with no data message. Having the data location, the client again connects to the server and requests the data itself.
- Data transformation tools - these tools are written combining C programming language and BASH scripting. They transform the downloaded data to our internal data format, which we use in the science model. Similar to the Data downloader tools, we again created 3 different transformation tools - one for each data server.
- The science model codes are written in Matlab and Fortran. These are the main processing tools and they exist in several modifications one for each data interpretation variant.
- Html file generator - this tool is created using combined C programming language and BASH scripting. Using predefined html template it processes the output data from the science model and generates html pages that are ready to be published on our server.
- Html publication tool - this is a simple tool that creates new folder on our web server and publishes there the final html results of the model.

III. SCIENTIFIC ACTIVITIES

The very detailed description of the performed investigations is avoided in this part of the present Report relying on the attached texts of publications, available online at http://space.nat.bg/list (see Appendix A: List of publications and presentations, supported by the EOARD Grant). There is only one paper [3] which is still in preparation at the moment of the submission of this report. The completed text of [3] will be introduced there within nearest 2 weeks. This is the reason to include in the list the short earlier work [3a], presenting some starting ideas of the studies, described in the Section 1 below.

1. Solar wind discontinuities identification based on single spacecraft plasma and magnetic field measurements

The problem of interplanetary shock waves study, based on single spacecraft plasma and magnetic field measurements has been extensively considered in the literature (see for instance some references below, cited in the paper [3]). Several important issues are addressed in quite different approaches in these papers, provided that we are dealing with certain, "somehow" already identified MHD interplanetary shock wave:

- How the Rankine-Hugoniot (R-H) relations are satisfied
- Best-fit procedures aiming better satisfaction of the (R-H) relations
- Determination of the shock normal orientation. Besides its own importance, this problem is crucial to the correct treating of the above two tasks. Quite a lot different approaches for the shock normal determination have been elaborated.
- Estimates of the errors in the mentioned above data analyses.

The attention in this project investigation is focused on:

a) the problem of automated detection of possible solar wind discontinuities in the plasma and magnetic field data time series;
b) identification of the discontinuities in terms of MHD classification ;
c) determination of the discontinuity's properties;

d) determination especially of the discontinuity normal, as one of the properties, but very basic one.

We separate here d) as a special different task, having in mind a kind of specific "loop" in the procedures from a) to d), requiring very careful organization of these procedures: The determination on the normal unit vector depends on the type of the detected discontinuity (shock wave, tangential and so on). But from other side we need first discontinuity normal as a starting point for its identification.

In addition, there is a variety of approaches for determining the normal vector itself, based on different sets of parameter measurements. Some widely used approaches are:

A. "Coplanarity theorem" normal determination, involving averaged values of the magnetic field components "before" and "after" the shock.
B. Several modifications of the coplanarity techniques (velocity-coplanarity; "mixed" coplanarity), utilizing some properties of the shock geometry and involving in the consideration, besides the magnetic field, also velocity vector components "before" and "after" the shock (Abraham-Shrauner, 1972, 1976)
C. Minimum variance techniques (Sonnerup and Cahill, 1967), making use of available multiple magnetic field measurements along the shock structure;
D. Methodology, proposed and modified in the papers of Vinas and Scudder, 1986 and Szabo, 1994, where the best-fit normal vector is obtained statistically, making use of the mass and momentum (R-H) relations, containing only plasma (velocity and density; or velocity, density and temperature) data.
E. There are approaches, similar in principle to that, mentioned in D., where a least-square techniques is applied to the whole (or almost whole) set f (R-H) equations in order to reach their best fit satisfaction, without separating special step for evaluating first the normal vector (e.g. Chao, 1970, Lepping and Argentiero, 1971).

In order to investigate the performance of the different approaches, the team of the project developed our "own" codes, modeling the above approaches B, C, D.

The currently operating identification procedures however (see Section 1a) are based on the approach A, as well on a new (now developed) "generalized minimum variance techniques". This techniques is described in [3] in more details. It is based on two main points:

(i) The eigenvalues (as well the eigenvectors) of the covariant matrix defined in the well known way by the components of the magnetic field vector, undergo an essential and character evolution "passing" through the discontinuity.

(ii) Quite the same is the situation with the covariant matrix, defined in analogical way by the velocity components.

Briefly described, the utilized now (in our web-site) discontinuity identification procedure (section 1a) comprises the following steps, performed over 2 hour segment of 1 min–averaged plasma and magnetic field data:

Step 1. Looking for possible discontinuities of forward or reverse type. Several different criteria are implemented "passing" them by 1 min step "slipping" over the whole data segment:

- Looking for "jumps" in the character MHD Mach numbers (fast magnetosonis, slow magnetosonic, Alfven, sonic). The same procedure is described in [3a].
- Looking for jumps simply in the dynamic pressure.
- Looking for discontinuity signatures, "caught" by specific sharp changes of the (minimum variance) covariant matrixes for both magnetic field and velocity. Points (i) and (ii) above.

Step 2. The procedure deals with each "candidate" for discontinuity, applying wavelet analysis for two different reasons:

- Determining the interval of the shock structure (limited by vertical dashed lines on the resultant figures in our web site). Similar procedure was utilized in the previous variant, described in [3a], but it is now completely modified, changing in particular the discrete wavelet analysis by continuous one.
- Wavelet procedure, determining in reasonable quantitative way the sub-intervals "before" and "after" the shock structure subinterval. In our knowledge this the first attempt for strong quantitative solution of this very sensitive problem. The conducted so far numerical tests with real satellite data are quite promising for the robustness of this new criterion.

Step 3. So obtained discontinuities candidates (already with "label" forward or reverse) are finally examined for determining their type, testing them against known from MHD theory typical properties. The assumption is made that **fast, slow as well intermediate shock waves** are physically meaningful shock waves. If the identification points to some "**nonevolution" shock wave** (possible theoretically), we admit non-unique identification, assuming that this event could be a **tangential discontinuity** as well. That's why in the working currently Internet variant in such case both possibilities for the same event are displayed (respectively, each with its own computed properties). It is worth noting that at this stage the algorithm distinguishing tangential from rotational discontinuities is not elaborated and not included in the acting programs. Some consideration and preliminary test were done however promising possible success in this direction.

Evidently it is worth doing future efforts on this particular topic having in mind its importance.

Used satellite data; peculiarities.

Three types of real satellite data were used in this study:

- WIND archive data (WD), taken online in our case from CDAW data base of NASA Goddard Space Flight Center (http : //cdaweb.gsfc.nasa.gov/istp public/). For identity all data sets are transformed to 1 min averages:

• 1 minute magnetic field data averages from WIND MFI Instrument
• 12 sec spaced in time electron moments derived from integration of solar wind electron distributions measured by the WIND/SWE VEIS instrument
• 3 sec ion moments from 3DP 3-D Plasma Analyzer, http : //sprg.ssl.berkeley.edu/wind3dp/

- ACE archive Level 2 data (AL2), taken from the same data base:
  - SWEPAM plasma (proton data)
  - MAG magnetic field data

- ACE archive Level 1 data (AL1), taken from http://sec.noaa.gov – available for the last 30 days:
  - SWEPAM plasma (proton data)
  - MAG magnetic field data

- ACE (near) real time data (ART), taken from http://www.srl.caltech.edu
  - SWEPAM plasma (proton data)
  - MAG magnetic field data

There are **differences between the above listed data sets**, some of them – quite substantial from the point of view of the applied "conventional" MHD consideration. As we utilize the concept of the single fluid MDH approach here, we may take the ion's gas mean velocity and density as the same parameters for the one-fluid mixture of the electrons and ions. It is known however, that the correct value for the effective one- fluid pressure (or temperature) is the sum of both (electron + ion) temperatures respectively.

- From this point of view the complete data set is available only in the WD case.
- The electron temperature is missing in all ACE cases: AL2, AL1 and ART cases
- In addition, in ART and AL1 cases, only one (X) velocity component is available. The ART is the only operating near real time data source from L1 now.

Discontinuities identification algorithm variants for each of these cases have been developed and tested. We decided not to use some “data fitting” algorithms in order to “recover” the missing parameters, supposing at this stage that this could introduce unacceptable uncertainties. We are rather trying to estimate the really introduced errors in the shock parameter’s estimates and identifications in each case [3]. The results seem to be that the temperature uncertainties, introducing errors through Mach numbers, affect the identification less then this is done because of missing velocity components Vy and Vz. The latter components are generally small (~<10% of the Vx), but the experiments with WD and AL2 data demonstrate that around the discontinuity they may become much more essential, affecting the normal vector orientation and thus, generally - the shock identification. This effect seems to be more considerable then the electron temperature is missing.

Some References from [3]:

Abraham-Shrauner, B, Determination of magnetohydrodynamic shock normals, J. Geophys. Res., 77, 736-739, 1972.

Abraham-Shrauner, B. and S. H. Yun, Interplanetary shocks seen by Ames Plasma Probe on Pioneer 6 and 7, J. Geophys. Res., 81, 2097-2102, 1976.

Acuna, M.H. and R.P. Lepping, Modfication to shock fitting program, J. Geophys.Res., 89, 11004-11006, 1984.

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Chao, J. K. and K. C. Hsien, On determining magnetohydrodynamics shock parameters $theta_{Bn}$ and M_A . Planet. Space Sci., 32, 641-646, 1984.

Kartalev, M. D., K. G. Grigorov, Z. Smith, M. Dryer, C. D. Fry, Wei Sun, and C. S. Deehr Comparative study of predicted and experimentally detected interplanetary shocks. ESA Publication, SP-477, 355-358, 2002

Lepping, R. P. and P. D. Argentiero, Single spacecraft method of estimating shock normal, J. Geophys. Res., 76, 4349-4359, 1971.

Szabo, A., An improved solution to the “Rankine-Hugoniot” problem. J. Geophys. Res., 99, 14737-14746, 1994.
Sonnerup, B. U. Ö., and L. J. Cahill Jr., Magnetopause structure and attitude from Explorer 12 observations, J. Geophys. Res., 72(1), 171-183, 1967.
Vandev D., K.Danov, P.Mateev, P.Petrov, M.Kartalev, Z.Smith and M.Dryer, Development of a real - time algorithm for detection of solar wind discontinuities , Astrophys. Space Sci., 120, 211-221, 1986
Vinas, A.F. and J. D. Scudder, Fast and optimal solution to the “Rankine-Hugoniot problem”, J. Geophys. Res., 91, 39-58, 1986.

1a. Discontinuities identification: Project’s results

The main result of this section of the project research, as well of the whole project is the creation of a web-page
http://space.nat.bg
which is remotely accessible automated instrument for studying solar wind behavior. This dynamic page is capable to serve simultaneously practically unlimited number of users. The access is open now (the web page is not advertised however), but it is possible to introduce (if AFRL will decide to) a password-permission access only.

The detailed description of the web page is omitted here, as the page is accessible and may be observed and its work checked in any time. For the convenience of the reader of this text several “ready” examples are provided at http://space.nat.bg/archive where some cases are taken from the ISTP Solar Wind Catalog of Candidate Events (http://pwg.gsfc.nasa.gov/scripts/sw-cat/Catalog_events.html)s. The web site contains three independently processing branches:

- Near real time monitoring of the solar wind at L1 using ACE near real time data. The system downloads periodically (30 min or shorter period) SWEPAM and MAG 120 min data interval from ACE data base; performs data processing and identification of the found discontinuities (if any), then displays the results. These results consist of
- Overview, showing the “place” of the discontinuities in the MHD classification table
- A table with estimated by the algorithm basic important properties of each discontinuity
- 12 plots presenting data time series during the considered interval, results of the wavelet analysis

- Interactive page for studying archive ACE data, where the user may select certain time moment (year, month, day, UT) with available in the NASA archive ACE data. The program automatically withdraws the needed data via Internet, performs the interpretation and displays the result in analogical to the real-time case fashion. There is an essential difference however: In this case all three velocity components are available (Level 2 data in the terminology of the ACE team) and, respectively, the results are more precise and adequate. The temperature (as well the pressure) is that of the ion component only.

- Interactive page for studying archive WIND data, where the user may select certain time moment (year, month, day, UT) with available in the CDAW NASA archive WIND data. The procedure is similar to the above described, but here the temperature and pressure are resultant ones of the mixture (electrons + ions). Respectively more results figures are displayed. For users' convenience we display there also WIND GSE coordinates. In addition, plots displaying in parallel variations of the ion / electron densities as well ion / electron temperatures are also presented in this set of plots. The latter may help in the interpretation of the studied solar wind structures.

As it was already mentioned, **the basic publication** devoted to the studies described in this section is in preparation at the moment of the submission of the Report and the ready draft will be soon added to the list of the relevant to the Project publications as #[3] in http://space.nat.bg/list.

1b. Discontinuities identification; Possible development

The above described identification algorithms, codes, web page require quite a lot not principal, but important **accomplishing conventional work** to be done. This is necessary mainly for the users' convenience:

- The problem of preliminary data processing (dealing with errors, gaps and so on), which is quite crucial in such an automated system is not so far resolved satisfactorily enough. There are too many instruments and data types used by the system with no provided thorough guides concerning these problems and a kind of "training" and setting work should be done additionally. Some substantial time is needed for elaborating these technical problems, ensuring

more reliable work of the system and avoiding some “unexpected bugs”, possible now.

- Another kind of conventional, but substantial further settings require the identification algorithms themselves. These are some “thresholds parameters”, organization of some logical loops and so on. Making use of arbitrary chosen or well established cases, a further “tuning” of these elements should improve the reliability of the automated system work.
- The need of accomplishing the above mentioned two groups of improvements was the reason to postpone at this stage the creation of our own archive of interplanetary discontinuities sweeping along the WIND and ACE data archives. This could be a reasonable task to be done in the future together with “checking” with our algorithms the existing lists of solar wind discontinuities prepared already by different scientific groups.

Our work during the project and the conducted testing experiments with new modified algorithms revealed that **some principal problems of discontinuities’ identification** in developed here approach also still exist and require further investigation:

- Considerable work was done in the frame of the project on the problem of error estimates and this is partially addressed in the paper [3]. This problem however needs further consideration & incorporating the theoretical estimates to the practical implementation in the real-time and interactive web – based identification procedures.
- Two particular aspects of the error-estimates issue have a very special self-dependent importance: (i) The errors caused in ACE Level 2 data case by missing of the electron temperature; (ii) The error caused in ACE Level1 (and real-time) cases, caused in addition by missing of the Vy and Vz velocity components.
- Our preliminary consideration pointed to a possible conclusion that the present general scheme of the identification procedure leads sometimes to unacceptably large errors because of the lack of the two velocity components. If it will be proved that this is really the case, we have to look for principal changing the concept (especially for this case), perhaps for introducing some best-fit procedure and so on. The importance of the real-time identification especially to the space weather implementation makes worthy such further efforts.
- Some very important further “tuning” developments of the identification procedures remain to be done. (This became clear after careful examination of the performance of the present variant of the system). The procedure distinguishes now quite reliably “the well defined” types of MHD shocks –

fast, slow magneto-sonic and intermediate forward and reverse shock waves. Further consideration however deserve the “separating logics” between tangential and (at least some) nonevolution MHD waves (in addition, the latter – with not very well proved physical meaning). And, what is even the most important, we found recently that probably both - tangential and rotational - discontinuities enter into the class “tangential” in the operating now variant of the procedure. The need of further development aiming their mutual distinguishing is evident.

2. Determination of the effective polytropic coefficient

2a. Project’s results

The problem of the determination of the effective polytropic coefficient of the solar wind was not among the preliminary planned to be considered problems. The importance of this artificially introduced parameter for indirect characterizing thermodynamic properties of the effective gas, modeling the solar wind plasma, is well known. From the point of view of this project’s tasks this parameter could provide essential additional information in identification of different solar wind structures, each of them affecting in a specific manner the space weather. That’s why when an idea for its determination, based on single spacecraft measurements arose, we decided to spend a lot of efforts on this problem, believing that this is not “a step aside” from the project’s subject. All the details are in the attached paper [2], submitted to JGR. Recently we received the first reviewers’ comments and a summary of the editor: *“Both reviewers find this work significant and potentially suitable for publication in the Journal of Geophysical Research - Space Physics, but they have a number of comments that first need to be carefully addressed.”* It seems that this paper will be rather accepted in JGR and we are thinking about its appropriate continuation and applications.

2b. Possible developments

The algorithm proposed and demonstrated in [2] is still in quite initial stage of development. Further investigation and work on the robustness of the scheme could create a useful instrument for solar wind monitoring. This instrument could be incorporated into interactive web pages dealing with ACE and WIND data

bases, searching appropriate intervals where the polytropic index estimate is possible. We may think (still cautiously) about the incorporating similar procedure even to the near-real time monitoring.

3. Effects on the Geospace environment

3a. Project's results

We are citing in the attached *List of publications and presentations, supported by the EOARD Grant* (http://space.nat.bg/list) two papers ([6] and [7] in http://space.nat.bg/list/) with acknowledgment to project's support. The **ionosphere electrodynamics phenomena** considered there also belong to the space weather paradigm (in its wider definition). They are even indirectly impacted (vie non-mentioned there chain of geospace mechanisms) by the solar wind peculiarities, monitored by our system.

The modeling experience and already developed numerical models of the Geospace Hydrodynamic Laboratory made possible to consider also some geospace phenomena, quite directly affected by solar wind flow. Thus, the results of a very detailed numerical **magnetosheath study and magnetosheath data interpretation** using our numerical models in the papers [4], [8], [9] (http://space.nat.bg/list/) are crucially dependent on the input solar wind parameters, taken from the ACE or WIND data bases.

The techniques for polytropic coefficient estimate (described in [2]) was applied in the presentation [5], where an attempt was made (possibly, the first in the literature) **to explain some "strange" unexplainable otherwise variations in the magnetosheath plasma flow** by changes in the polytropic coefficient in the oncoming solar wind flow.

3b. Possible developments

A very realistic possibility exists for closer incorporation of the results of the present project (& their further modifications) into the implementations of the developed in the Geospace Hydrodynamics Laboratory self-consistent magnetosheath-magnetosphere numerical model.

- Thus, it is possible to develop a kind of extension of the developed by now interactive (or near real time) web-based observation and interpretation of the WIND and ACE solar wind data, running in addition the magnetosheath-magnetosphere model with input data corresponding to the considered time moment.
    - The simplest variant of such a procedure presumes the conventional "time shifting" of the (WIND or ACE) solar wind data to the magnetosheath position, taking into account just the solar wind velocity.
    - Provided that the solar wind discontinuities as well their properties (including the speed!) are known, the above procedure may be done much more adequately, taking into account also possible jump's arriving time to the magnetosheath.
- As mentioned in Section 3a, the influences of the polytropic index changes on the magnetosheath could be considered separately as a very essential task. The reason is that these variations may lead to dramatic variations in the magnetosheath shape (mainly changing the bow shock position).
- Finally, some minor extension of our magnetosheath model (not yet done), including calculation of the magnetic field distribution within the magnetosheath in the frame of the widely used gas dynamic convective field (GDCF) approach, could provide also the electric field distribution. As our magnetosheath model describes the 3D magnetopause shape with details like cusp indentations, the obtained in such a way magnetosheath electric field distribution over (or near) the magnetopause could be very useful in understanding the mechanisms of solar wind influence on the near-Earth environments.

4. Study of solar wind structures

4a. Project's results

As preliminary planned, an essential part of the efforts, not directly connected to the development of the web-based system, were devoted to the further justification of the extensively used in the literature "pressure pulse" CME/IP models (e.g. Hakamada-Akasofu-Fry Solar Wind Model (HAFv.2): Fry et. al., 2001, cited in [1]). A "beta version" of the considered in this Report identification system was utilized in order to identify about 200 solar wind discontinuities monitored by ACE spacecraft at L1 as an essential part of this paper, recently accepted for publication in JGR. One team member is among the co-authors and two other are acknowledged for their substantial contribution. We omit here describing this study, providing the paper's [1] text http://space.nat.bg/list

4b. Possible developments

- There are plans (and even initiated work) for the continuation of the study started in [1]. Some secondary effects (like particles acceleration) caused by the shocks detected at L1 and strongly dependent on the shocks' properties will be addressed.
- It is known that the complex **satellite study of the details of the solar wind structure**s (CMEs, magnetic clouds and so on) relies substantially on knowing the changes ("passing" over this satellite) of the solar wind properties and especially on passing of strong discontinuities with certain characteristics. Though the MHD approach is far from the thorough explanation of these structures, the extensive (even automated) implementation of the techniques developed in this Project could be very useful element of these studies.

SUMMARY

We report the results of one year work on the development of a new techniques in space weather forecasting. A complex Internet based hardware / software system was designed providing to the remote users automated access to ACE and WIND solar wind data bases as well data interpretation from point of view of the existence and the properties of the solar wind discontinuities (http://space.nat.bg). A near real-time system's branch performs a monitoring of the real-time available ACE plasma and magnetic field data measured at L1 libration point. An assumption is made of the validity of MHD single-fluid approach for the solar wind modeling. The developed and some modified earlier existing algorithms ensure quite robust detection in the data time series and identification/classification of the fast, slow and intermediate MHD shock waves revealing also their characteristics. The system classifies also non-evolution shocks, tangential/rotational discontinuities. The latter classification needs some further elaboration. The most reliable seems to be the interpretation based on WIND data, containing all needed information for treatment in a single fluid MHD approach. There is a lack of electron temperature in ACE data and two of the velocity components in the Level 1 & real time ACE data.

We report in addition scientific activities, supported by the project, directly or indirectly related to the main project's task. An essential part of this work was devoted to the further justification of the extensively used in the literature "pressure pulse" CME/IP models. The team started systematic efforts in incorporation of the developed in the frame of this project instruments for solar wind monitoring to the magnetosphere/magnetosheath numerical model created in the Geospace Hydrodynamics Laboratory of the Institute of Mechanics, BAS. The study of the nature of different solar wind structures originated a new idea for estimates of the effective polytopic index of the solar wind flow.

We present as auxiliary results 8 papers acknowledging the project (& one in preparation) including one accepted in JGR and one with good first reviews in JGR.

We believe that some of the project's tasks deserve evident continuation / accomplishing the presented work, as described in Sections: III 1b, 2b, 3b, 4b of the Report. The proposed there activity could essentially improve the system capability as a space weather monitoring/forecasting system, helping scientists in a wide spectrum of research activities, increasing the work efficiency of the already designed, enough powerful for solving these problems, hardware platform. We are convinced that one more year project's continuation with similar financial support (withdrawing ~$3400 equipment cost) could be an excellent possibility to the team to reach much better system usefulness.

Appendix A

List of publications and presentations, supported by the EOARD Grant
http://space.nat.bg/list

[1] S.M.P. McKenna-Lawlor, M.Dryer, M. D. Kartalev, Z. Smith, C.D. Fry2, W. Sun, C. S. Deehr, K. Kecskemety, and K. Kudela, Near real-time predictions of the arrival at Earth of flare-generated shocks during Solar Cycle 23, J. Geophys. Res. (accepted) 2006.

[2] M. Kartalev, M. Dryer, K. Grigorov, E. Stoimenova. Solar wind polytropic index estimates based on single spacecraft plasma and interplanetary magnetic field measurements, Submitted to J. Geophys. Res. (2006).

[3] M. Kartalev, K. Grigorov, M. Dryer, L. Bundova, E. Stoimenova. Automated algorithms for shocks' identification based on single spacecraft plasma and interplanetary magnetic field measurements. In preparation

[3a] M. D. Kartalev, K. G. Grigorov, Z. Smith, M. Dryer, C. D. Fry, Wei Sun, and C. S. Deehr Comparative study of predicted and experimentally detected interplanetary shocks. ESA Publication, SP-477, 355-358, 2002.

[4] M. Kartalev, S. Savin, E Amata , P. Dobreva, G. Zastenker, and N.Shevyrev. Magnetopause cusp indentation: an attempt for a new model consideration, ESA SP-598, January 2006.

[5] M. Kartalev, S. Savin, P. Dobreva, E Amata. Self consistent gasdynamic model versus "strange" boundaries and structures in magnetosheath. Presented at the European Geosciences Union General Assembly 2006, Vienna, Austria, 02 – 07 April 2006.

[6] M.D. Kartalev, M.J. Rycroft, M. Fuellekrug, V.O. Papitashvili, V.I. Keremidarska. A possible explanation for the dominant effect of South American thunderstorms on the Carnegie curve, JASTP, 68, 457-468, 2006

[7]. M. J. Rycroft. M. D. Kartalev, V. O. Papitashvili, V. I. Keremidarska On the effect of near-equatorial thunderstorms on the global distribution of ionospheric potential., Adv. Space. Res., 35, 1450-1460, 2005.

[8]. P. Dobreva, N. Shevyrev, A. Koval, G. Zastenker, M. Kartalev. Application of new magnetosphere-magnetosheath model t analysis of satellite magnetosheath measurements. Proc Nat. Congress Theoret. Appl. Mech., Varna, 2005

[9] P. Dobreva, N. Shevyrev, A. Koval, Kartalev, G. Zastenker. Interpretation of satellite magnetosheath plasma measurements using a magnetosheath-magnetosphere numerical model, JTAM, (in press) 2006..